BELLCOMM, INC.

COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE – Aperture Masks for Range Measurements with One Surveyor TV Camera

TM – 66-1012-4

FILING CASE NO(S) – 340

DATE – March 10, 1966

AUTHOR(S) – P. L. Chandeysson

FILING SUBJECT(S) – (ASSIGNED BY AUTHOR(S) – Surveyor
Site Survey

ABSTRACT

Two methods of measuring range with a single Surveyor TV camera by using special aperture masks in front of the lens are described in this paper. The aperture masks, which could be mounted in the camera filter mechanism, allow light to enter only certain parts of the lens. The masks can be designed to increase the accuracy of the current range measuring technique or to produce a special image which is the basis of a new range measuring technique.

The first method uses a mask which admits light only through sector shaped openings on opposite sides of the lens. This mask reduces the depth of field of the lens. It would be used when measuring range by the focus-ranging technique, since the accuracy of focus-ranging increases as depth of field is reduced.

The second method uses a mask which admits light through two slits in front of the lens. This mask produces double images which are separated by distances inversely proportional to range. By measuring the separation distance on the picture, the range to objects in the field of view can be calculated from a simple formula.

The effect of these aperture masks was demonstrated using a film camera to simulate the Surveyor TV camera.

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(NASA-CR-156371) APERTURE MASKS FOR RANGE MEASUREMENTS WITH ONE SURVEYOR TV CAMERA (Bellcomm, Inc.) 9 p

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SUBJECT: Aperture Masks for Range Measurements with One Surveyor TV Camera - Case 340

DATE: March 10, 1966

FROM: P. L. Chandeysson

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TECHNICAL MEMORANDUM

I. Introduction

Focus-ranging is one method proposed for range measurement with a single Surveyor TV camera. Objects in focus in the picture are considered to be at the range indicated by the lens focus-distance setting. This technique has two important limitations:

(1) it gives no positive information about the range of objects which are not in focus; therefore, a series of pictures at various focus settings is needed to establish the range of all the objects in the field of view;

(2) it requires that the largest lens opening (F/4) be used to limit the depth of field enough to provide reasonable range measuring accuracy; therefore, a light reducing filter is necessary to prevent over exposure with bright subjects.

Filters are provided on the Surveyor TV camera for colorimetric and polarimetric measurements. These filters can be placed in front of the lens by earth command, and could be used to reduce the light entering the lens so that focus-ranging measurements could be made of bright subjects. However, these filters uniformly attenuate the light entering the lens aperture, and the possibility of designing a special "filter" which increases the capability of focus-ranging by selectively attenuating or blocking light rays entering different parts of the lens suggests itself. Two applications of such ranging filters or masks are considered in this paper.

II. Effects of Lens Aperture Masks

Except for the effects of diffraction and lens abberrations, light from a point on a subject in focus falls on a single point on the light sensitive surface of the camera. If the subject is out of focus, the light from a single point is spread over a small "circle of confusion" - provided that the lens aperture is circular. If an opaque sector-mask, shown in Figure 1, is placed in front of the lens, the circle of confusion will be broken up into two "sectors of confusion" corresponding to the uncovered sectors of the lens. Out-of-focus images formed from these double sectors of confusion would probably appear more out of focus than images formed by circles of confusion since the best image-forming rays through the center of the lens are blocked. The light from objects which are in focus would still be correctly focused on the light sensitive surface. The effect would be to reduce the depth of field of the lens.

Since reducing the depth of field of the lens proportionally increases the accuracy of focus-ranging, the sector-mask should be used during focus-ranging whenever enough light is available to properly expose the vidicon. Focus-ranging for dim subjects would have to be performed without benefit of the sector-mask because of the large amount of light it obscures.

A different single camera range measuring technique is based on the double image produced by the slit-mask shown in Figure 2. If the camera lens is focused at infinity, only light rays from objects at infinity will converge on the light sensitive surface. Light rays from objects closer to the camera will fall on two separate spots on the light sensitive surface, as shown in Figure 3. Since the slits are narrow compared to the diameter of the lens, double images which are well defined in the direction perpendicular to the slits are formed on the light sensitive surface. The distance between these images is inversely proportional to range. This provides a means of measuring range to all objects in the field of view with one photograph.

The separation of the images and an estimate of the range accuracy of this technique can be found from the double image ray geometry of Figure 3. The distances shown are:

S = the range of the subject

S' = the image distance of the subject

f = the lens focal length

b = the slit separation

e = the double image separation

From similar triangles:

$$\frac{e}{b} = \frac{S'-f}{S'} = 1 - \frac{f}{S'}, \tag{1}$$

From the image distance formula:

$$\frac{1}{f} = \frac{1}{S} + \frac{1}{S'}$$

$$\text{or } 1 - \frac{f}{S'} = \frac{f}{S} \qquad (2)$$

Substituting: $e = \frac{fb}{S}$

$$\text{or } S = \frac{fb}{e} \qquad (3)$$

The range is inversely proportional to the separation of the double images, with the constant of proportionality being the product of focal length and slit separation. If f and b are known accurately, the range error depends on the accuracy to which the image separation can be measured and the range of the subject.

$$\left|\frac{\Delta S}{S}\right| = \frac{S}{fb}\,\Delta e$$

Relative range error is proportional to range and image separation measuring error. Assuming the accuracy of measuring image separation is limited only by the size of the Surveyor TV resolution element (.025mm), and that the slit spacing is 20mm with the 100mm focal length lens, the relative range error is:

$$\frac{\Delta S}{S} = 0.0125S$$

where S is the range in meters.

Focus-ranging accuracy (at F/4 without an aperture mask) has been estimated* to be:

$$\frac{\Delta S}{S} = 0.0073S$$

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*"Measuring Range from Surveyor Camera Focus Settings", P. L. Chandeysson, Bellcomm Memorandum For File, September 16, 1965.

The expected accuracy of the double image technique is only about half that of the focus-ranging technique. However, all range information is obtained from a single picture, and the range accuracy does not depend on the calibration of the focus distance telemetry system. The operational advantages of double image ranging, particularly as a preliminary step for focus-ranging, are evident.

III. Demonstration of Aperture Mask Effects

To demonstrate that lens aperture masks produce the effects described in the preceding section, an experiment was performed using a film camera to simulate the Surveyor TV camera. Some care was taken to simulate the image quality of the TV camera; angular field of view and angular resolution were reproduced, and a low contrast subject and processing were used to reduce the tonal range of the prints. The limitations of this experiment are recognized; however, the results are interpreted as indicating that aperture masks may be useful for range measurement with the Survey TV camera.

A camera equipped with a 127mm, F/4.5 lens was used. This is similar in size and speed to the 100mm, F/4.0 lens of the Surveyor TV camera. Photographs were taken on fast panchromatic film, fine grain developed to a gamma of ~ 0.7 and enlarged 6 diameters. The subject was a series of bricks standing on a grassy slope shown in Figure 4. The closest brick, of which only the top is visible, is at 20 feet; the succeeding bricks are at 25, 30, and 40 feet. A black bar resolution chart was placed at 33-1/3 feet. At this distance, the bars subtend the angles indicated in Figure 5. Figure 4, which was taken with the lens stopped down, indicates the angular resolution of these photographs is approximately 1/4 milliradian - equal to the specified angular resolution of the Surveyor TV system with the lens focal length set to 100mm.

To demonstrate that the sector-mask reduces depth of field, a photograph was taken with the lens focused on a round white rock at 27 feet, and stopped open to F/4.5. The depth of field in this picture, Figure 6, was calculated to extend from 25 to 30 feet. The bricks at 25 and 30 feet appear in focus, and the brick at 20 feet and the resolution chart at 33-1/3 feet are slightly out of focus. With the sector-mask in place, the depth of field is reduced, Figure 7. No quantitative estimate of the reduction was made, but the result is evident.

To demonstrate that the slit-mask produces double images whose separation is inversely proportional to range, Figure 8 was taken with the lens focused at infinity, stopped open to F/4.5, and a slit-mask in front of the lens. The measured distance between the slits was 22.2mm. According to equation 3, the range can be calculated as $S = \frac{55.5}{e}$, where S is in feet and e is in mm.

The distances between the double images shown in Figure 8 were measured with a scale under a low powered magnifier. The results are shown in the following table.

Object	Actual Distance (feet)	Image Separation (mm)	Measured Distance (feet)
Brick	40	1.4	40
Resolution chart	33.3	1.8	31
Brick	30	2.0	28
Brick	25	2.2	25

IV. Conclusion and Recommendation

The use of lens aperture masks has been shown to produce effects which may be useful in measuring range with a single Surveyor TV camera. A sector-mask was shown to reduce depth of field, thereby increasing the accuracy of focus-ranging. A slit-mask produces double images from which the range of objects can be measured directly. The effectiveness and applicability of these techniques should be investigated further if it is desired to make maximum use of a single TV camera on Surveyor.

Paul L Chandeysson

1012-PLC-csh P. L. Chandeysson

Attachment
Figures 1 thru 8

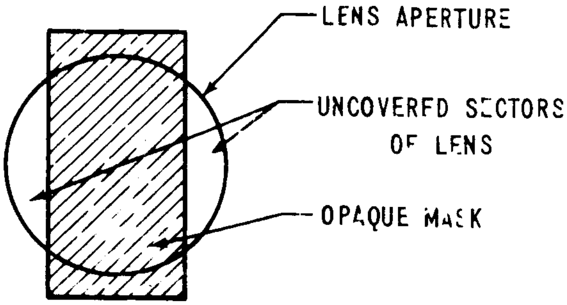

FIGURE 1 SECTOR MASK

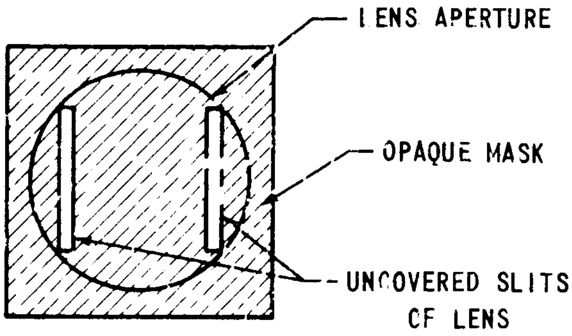

FIGURE 2 SLIT MASK

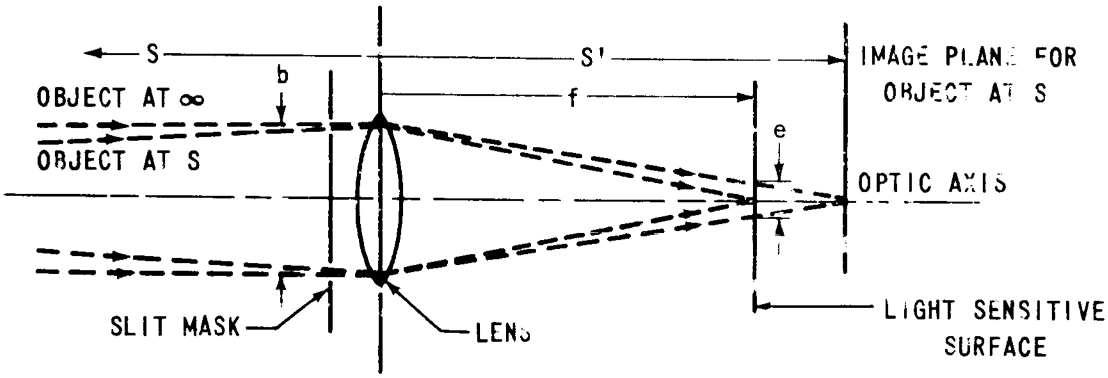

FIGURE 3 DOUBLE IMAGE RAY GEOMETRY

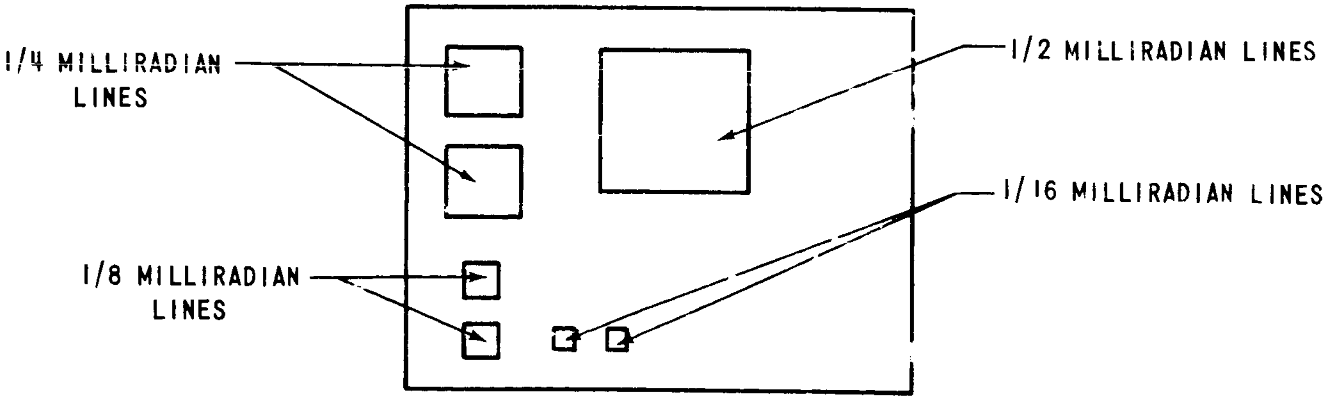

FIGURE 5 BLACK BAR RESOLUTION CHART

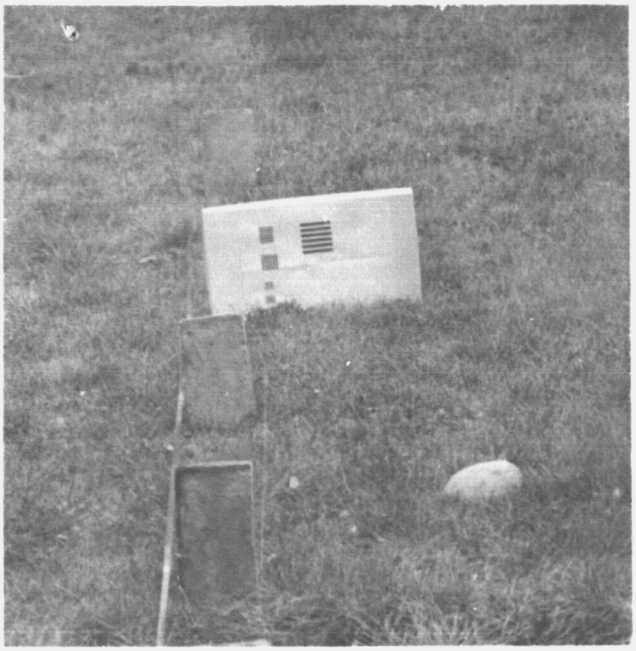

Figure 4
F/11, 1/80 Sec., No Mask
Focus at 33 1/3 ft.

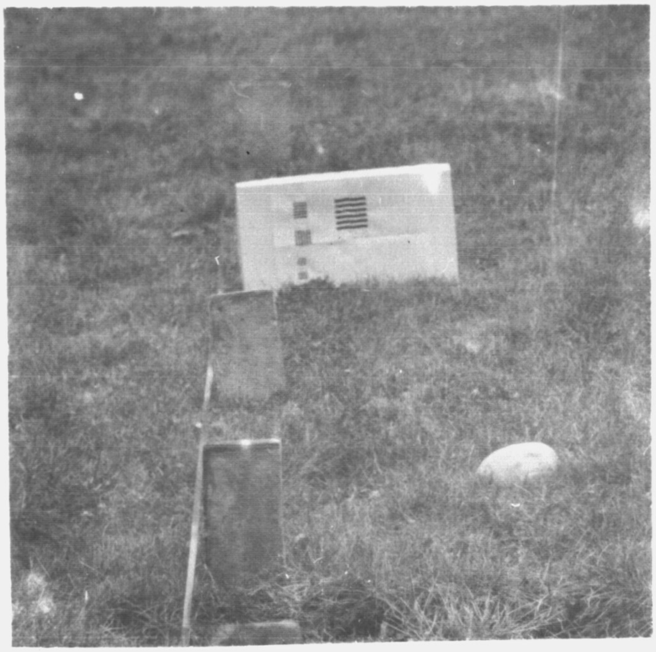

Figure 6
F/4.5, 1/500 Sec., No Mask
Focus at 27 ft.

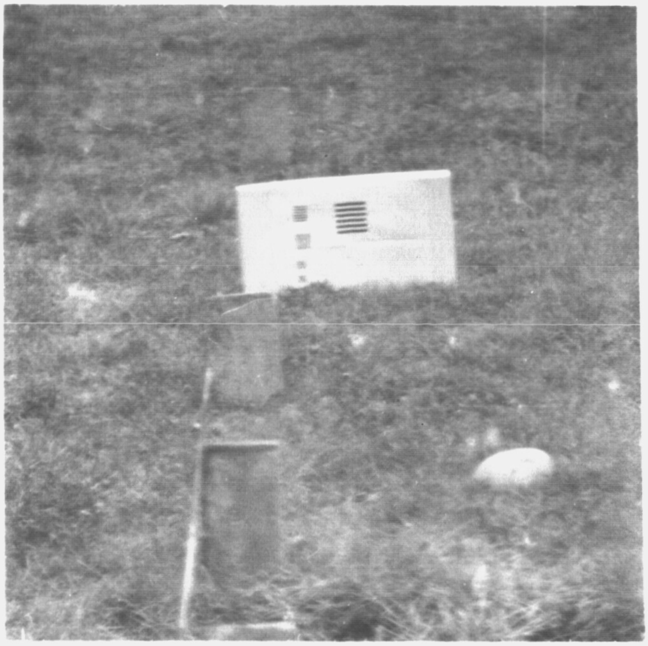

Figure 7
F/4.5, 1/80 Sec., Sector-Mask
Focus at 27 ft.

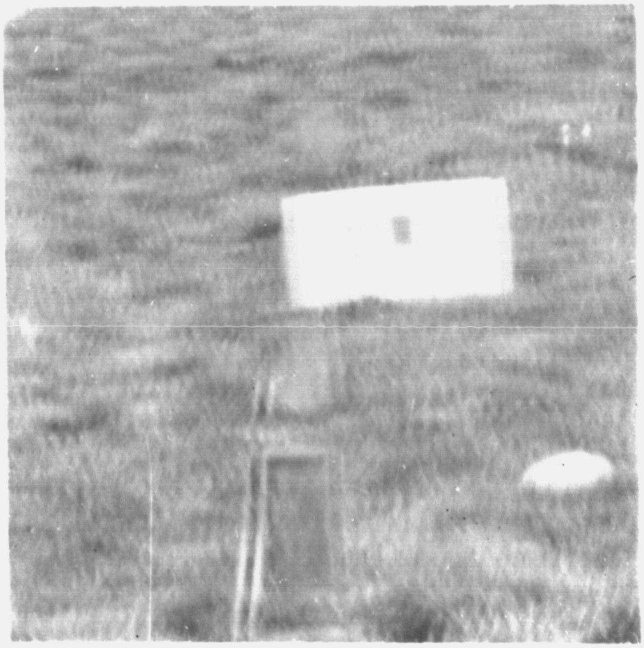

Figure 8
T/4.5, 1/40 Sec., Slit-Mask
Focus at Infinity

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